Satellite Remote Sensing of Large Scale Ocean Transients

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LONG-TERM GOALS

Our goal is to attain improved understanding of mesoscale, ocean surface transient response on time scales of days and longer using satellite observations of SST, topography, color and wind stress. This involves improved measurements of ocean temperature, color and topography fields determined by satellite observations.

OBJECTIVES

The objectives include the study of transient behavior of western boundary currents and associated eddy structures, frontal processes, and their response to atmospheric forcing as observed by satellite remote sensing techniques. Attainment of these objectives requires development and implementation of quantitative assimilation methods for satellite data on both large and small scales supported by suitable tools that yield timely access to calibrated, navigated satellite observations. A critical prerequisite is a clear understanding of the accuracies of the satellite-derived fields, and we have focused on the determination of the accuracy of infrared measurements of the sea-surface temperature.

APPROACH

Efforts have focused on the calculation of the individual components of the heat budget for the Arabian Sea, ongoing improvement of IR radiometer calibration and atmospheric correction techniques; continuation of global AVHRR LAC and GAC collection; and operation of this global retrieval capability for the ocean science community using the DOD/ONR furnished satellite receiving system. The accuracies of SSTs derived from the AVHRR (Advanced Very High Resolution Radiometer) using the Miami Pathfinder atmospheric correction algorithm are established by comparison with skin (radiometric) surface temperatures measured by a ship-board Fourier Transform Infrared Interferometer.

WORK COMPLETED

We have completed a comparison of Pathfinder SSTs and skin temperatures derived by the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI), and, in collaboration with Dr. Brian Ward of the University of Bergen, have demonstrated the synergy of data derived from the M-AERI and an autonomous, profiling buoy that measures temperature microstructure in the upper ocean.

RESULTS

The continuing research during the current contract period has four foci: a) remote sensing of the heat budget of the Arabian Sea; b) radiometric validation of AVHRR SST retrievals; c) a proof-of-concept cruise using two instruments together for the first time (M-AERI and SkinDeEP) to measure the ocean skin temperature and near-surface temperature gradients; and d) atmospheric radiative transfer modeling to derive coefficients for the atmospheric correction for the retrieval of SST from the GOES Imager infrared channels.

Heat budget of the Arabian Sea

Work has concentrated on calculating the individual components of the heat budget of the Arabian Sea:

1) Monthly multi-year means of *in situ* mixed layer depth have been obtained from Dr. Robert Molinari, and averaged to form seasonal estimates.

2) Monthly and seasonal estimates of the diffuse attenuation coefficient from the latest reprocessing of CZCS data are almost complete. Programs have been written to take almost seven years of daily global water-leaving irradiances and reduce the data to just the Arabian Sea, and only those days for which there are data in the region. Various methods for choosing how to average the data into monthly and seasonal fields have been explored (arithmetic average, bootstrap techniques, most common value, median, *etc*).

3) The bootstrap technique is being investigated as a method to improve estimates of the individual heat budget terms, and to get a better grasp of the associated error fields. Terms such as the SST, latent and sensible heat fluxes, and the diffuse attenuation coefficient are all possible candidates for the technique.

4) An equation to calculate the entrainment velocity at the mixed layer base (due to Kraus and Businger, 1994, referenced in Lee *et al.*, 2000) is being considered, using averaged monthly wind stress fields by Jones et al (1994), Florida State University.

5) Exchange of emails has been ongoing, in the hope of getting permission to use the monthly thermocline temperature fields from K.G. Radhakrishnan *et al*. (1997). These fields are necessary to compute the temperature change due to vertical turbulent diffusion, and the change due to entrainment.

M-AERI validation of the Pathfinder AVHRR SST retrievals

For SST retrievals from a well-calibrated spacecraft imaging infrared radiometer, the limit of the accuracy is imposed by the effectiveness of the atmospheric correction algorithm. The conventional approach to validating the SST fields is by comparison with in situ, bulk temperatures measured, for example, from drifting buoys, but this may include a significant contribution from skin layer and diurnal thermocline effects, that introduce gradients between the bulk temperature and the radiating, skin of the ocean. The consequences of these effects are conventionally attributed to imperfections in the performance of the atmospheric correction algorithm, i.e. are included in the uncertainties in the satellite-derived SST fields. To investigate the magnitude of these, comparisons were made between the Pathfinder SST derived at RSMAS from AVHRR data and a radiometrically-derived skin SSTs from the Marine-AERI (see below). Results from several cruises in a range of tropical and mid-latitude conditions (Figure 1, Table 1) show that more than half of the conventionally-derived uncertainties in the AVHRR SSTs (~0.5K) is attributable to the near-surface temperature gradients, with the accuracy of the atmospheric correction being ~±0.3K about a bias of ~0.1K or less, reflective of the average skin-bulk temperature difference (Table 2).

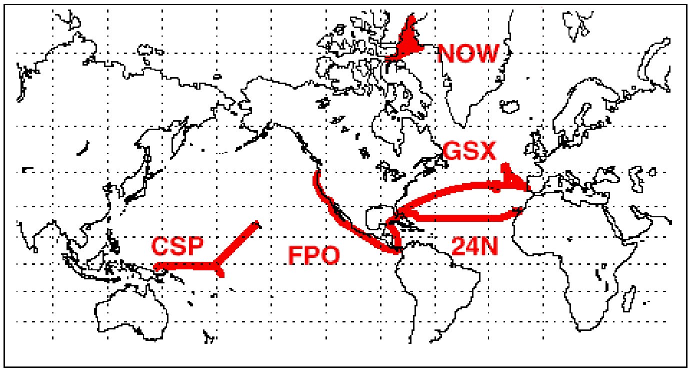

Figure 1. The areas of the cruises used in the radiometric validation of the Miami Pathfinder SST retrievals. The acronyms for each cruise are given in Table 1.

Table 1. Cruises used in the radiometric validation of the Miami Pathfinder SST fields.

Cruise Name	N	Mean K	St. Dev. K
CSP 1996	23	0.16	0.20
24N 1998	16	0.03	0.18
GASEX 1998	168	-0.01	0.25
FPO 1998	47	0.27	0.40
NOW 1998 (Arctic)	176	0.24	0.44
Total, all data	430	0.13	0.37
Total, excluding NOW data	254	0.06	0.29

Table 2. Results of the radiometric validation of the Miami Pathfinder SST fields. The means errors are expressed as Pathfinder SST – M-AERI SST.

Cruise Name	Ship	Year	Days
Combined Sensor Program (CSP)	NOAAS Discoverer	1996	78-103
24^{o}N Section (24N)	NOAAS Ronald H. Brown	1998	8-55
GASEX '98 (GSX)	NOAAS Ronald H. Brown	1998	127-188
Florida-Panama-Oregon transit (FPO)	NOAAS Ronald H. Brown	1998	196-210
North Water Polynya '98 (NOW)	CCGS Pierre Radisson	1998	150-203

M-AERI and SkinDeEP deployment

During October 1999, a three-week cruise took place off Baja California on the R/V *Melville*. This was a multi-disciplinary cruise led by Dr Dennis Clarke of NOAA. It provided the first opportunity to use the M-AERI (Minnett *et al.*, 2000) in conjunction with a new autonomous profiler called the Skin Depth Experimental Profiler (SkinDeEP; Ward and Minnett, 2000), to explore whether they produced compatible data useable for the study of diurnal and skin layer effects. SkinDeEP successfully made several hundred profiles through the uppermost five meters or so of the ocean, each time penetrating the surface. For this first deployment the profiler carried a microthermometer that produced temperature profiles as shown in Figure 2. Figure 3 shows a comparison of the SkinDeEP profiles with the M-AERI skin temperatures. (Figures courtesy of Dr Brian Ward, University of Bergen, Norway).

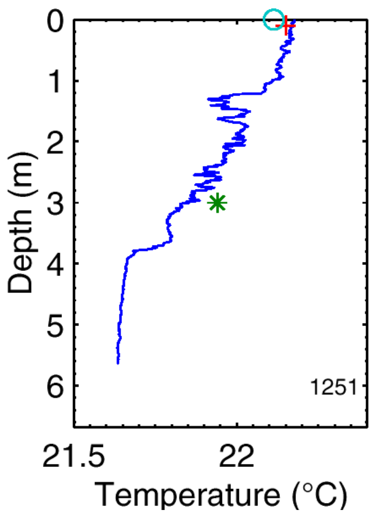

Figure 2. A temperature profile (blue) measured by a microthermometer on the SkinDeEP profiler at 1251 (local time) on 4 October 1999. The blue circle is the skin temperature measured by the M-AERI and the red cross a in situ temperature measured at a depth of about 5cm from a surface float. The green star is the temperature measurement from a thermosalinograph on the ship at a nominal depth of 3 m. The profiler reveals significant structure in the near-surface layer not resolved by the data at discrete levels.

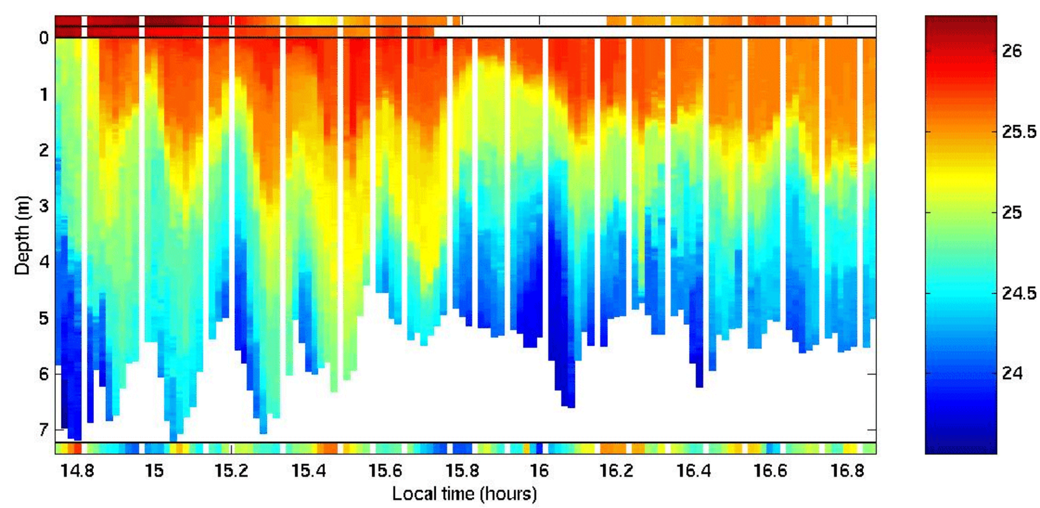

Figure 3. Time series of profiles measured by a microthermometer on SkinDeEP on 12 October 1999. The color bar at right gives the temperature scale. The top color ribbons show the temperatures measured by the M-AERI (skin- top) and float (~0.05m - below). The ribbon at the base of the plot shows the ship's thermosalinograph temperature at ~3m. The oscillatory structure evident in the profiler data are probably the result of Langmuir cells that were observed in the area.

***GOES SST Algorithm*.**

The derivation is underway of an atmospheric correction algorithm for GOES infrared imager data to derive accurate measurements of the ocean skin temperature to support a study of the diurnal signals of SST in near-coastal US waters. The radiative transfer model is based on that of Závody *et al*. (1995) to derive the algorithm for the Along-track Scanning Radiometer (ATSR) and subsequently modified at RSMAS for the development of the at-launch SST retrieval algorithm for the MODIS (Moderate-resolution Imaging Spectroradiometer on the NASA Terra satellite). The profiles used to describe the range of variability of the atmospheric state are derived from a set of quality-controlled radiosondes and from the output of the ECMWF assimilation model.

IMPACT/APPLICATIONS

The demonstration that the absolute accuracy of the Pathfinder SSTs is about 0.3K, rms, about a mean of <0.1K, i.e. about half the level of previous determinations using *in situ* sensors is an important result for all users of the Pathfinder SST fields. This means that many application of satellite-derived SSTs that were previously discounted because of the perceived inaccuracies of the fields can in fact be undertaken with increased confidence.

TRANSITIONS

The Pathfinder SSTs, which are distributed through the NASA JLP PO-DAAC, are very widely used in the oceanographic and climate research communities, and the recognition of their accuracies is likely to support increased and more diverse applications.

RELATED PROJECTS

This project has benefited from related research being done in the Remote Sensing Group at RSMAS with funding from other federal agencies. Specifically, the development of the M-AERI has been funded through a NASA contract, which has also supported the at-sea data collection on the 24N and FPO cruises shown in Figure 1. Other cruises were supported through other, related grants: the CSP by DOE through the ARM Program; NOW by NSF and NASA; GSX by NOAA. The development of the SkinDeEP profiler was funded through a grant to Dr B. Ward by the Norwegian Research Council, and the sensors were purchased with funding from NASA. Dr Ward's participation in a M-AERI cruise was also supported by NASA.

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